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AI-Driven Image Analysis for Enhancing Audits in Food and Beverage Industries Under GMP and SSOP Standards

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Abstract

This study evaluated the application of artificial intelligence (AI)-driven image analysis for enhancing Good Manufacturing Practices (GMP) and Sanitation Standard Operating Procedures (SSOP) audits in food and beverage (F&B) catering services. Three industrial F&B establishments located in Jakarta, Cikarang, and Karawang were assessed. Images capturing key visual criteria were analyzed using an AI system based on ChatGPT-4o, with compliance scored under three different prompt formulations to evaluate AI sensitivity. Manual audits conducted by trained auditors served as a benchmark. Statistical analysis revealed that AI assessments closely aligned with manual audits across most criteria, particularly for cleanliness of food-contact surfaces, personal hygiene, and pest exclusion. However, significant prompt-induced differences were found in more interpretative criteria such as facility design and storage practices. When averaged across stable prompts, AI scores showed strong agreement with manual audits, although AI tended to assign slightly stricter scores in certain areas. No significant differences were found in SSOP compliance evaluations, indicating high consistency for sanitation-related assessments. These results demonstrate that AI-driven image analysis can reliably support GMP and SSOP audits for visually detectable parameters, improving audit efficiency, objectivity, and frequency. Nonetheless, non-visual aspects such as documentation and microbiological testing still require human oversight. Integrating AI into food safety auditing represents a promising advancement for modern F&B compliance monitoring.

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Introduction

In the food and beverage (F&B) industry, particularly in mass catering services that provide large-scale meal production for institutions, factories, and corporate clients, maintaining stringent hygiene and food safety standards is critical. Good Manufacturing Practices (GMP) and Sanitation Standard Operating Procedures (SSOP) are essential frameworks to ensure food safety, hygiene, and quality (Alghaniya & Fitriani, 2023). Audits to verify GMP and SSOP compliance are typically conducted by internal quality assurance teams, third-party auditors, or government inspectors. These audits are usually performed on a periodic basis, ranging from monthly to semi-annually, and involve on-site evaluations that assess parameters such as facility cleanliness, employee hygiene, equipment sanitation, pest control, and documentation of procedures. At the global level, these practices are standardized through the Codex Alimentarius guidelines, particularly the CAC/RCP 39-1993 Code of Hygienic Practice for Precooked and Cooked Foods in Mass Catering (Codex Alimentarius Commission, 1993). This Codex document serves as a foundational reference for many national food safety regulations, including those implemented in Indonesia. Indonesia's national adaptation of these international standards is reflected in Ministry Regulation No. 75/M-IND/PER/7/2010, which outlines 18 GMP requirements—ranging from facility design, sanitation, and supplier control to pest management and documentation (Ministry of Industry of the Republic of Indonesia, 2010; Rohmah et al., 2023). SSOP complements GMP by detailing 10 operational procedures to maintain sanitation standards and align with international quality systems like ISO 9000:2008 (Ardhanawinata et al., 2023; Ristyanti & Masithah, 2021). Food safety involves preventing contamination, and consistent application of SSOP is crucial in safeguarding hygiene and product quality across the food supply chain (Government of the Republic of Indonesia, 2019; Indriani et al., 2021). The urgency for integrating technology-based audits is amplified by the increasing demand for food safety assurance. Incidents of foodborne outbreaks linked to improper handling, inadequate sanitation, and non-compliance with hygiene standards have prompted stricter regulations and heightened consumer expectations (Pakdel et al., 2023). In particular, the food and beverage (F&B) industry, especially catering services that provide daily meal supplies for industrial vendors, must uphold high standards of food hygiene and safety. For these F&B catering businesses, compliance with GMP and Sanitation SSOP is not only a regulatory obligation but also a critical factor for ensuring business continuity, maintaining client trust, and securing a competitive advantage.

Maintaining consistent compliance with GMP and SSOP in the food and beverage (F&B) industry is no easy task. High production volumes, shifting work schedules, and diverse operational settings all contribute to the complexity (Germinarqi & Purnomo, 2023). Although manual audits remain the standard approach for evaluating compliance, they are often time-consuming, labor-intensive, and susceptible to subjective interpretation by auditors. Moreover, because audits are typically conducted infrequently, their findings represent only a snapshot in time, and standards can vary depending on who conducts them—whether internal staff, buyers, or third-party agencies (Hutchinson et al., 2024; Powell et al., 2013). This challenge becomes even more pronounced in routine or follow-up audits, usually performed every one to six months, which tend to focus on observable hygiene aspects such as cleanliness, equipment storage, and employee protective gear. While still valuable, physical (on-site) audits have clear limitations—they require significant time, cost, and manpower, particularly for businesses with multiple sites or frequent evaluations (Kotsanopoulos & Arvanitoyannis, 2017). Travel, scheduling, and operational disruptions further reduce their practicality. In contrast, remote or AI-assisted audits offer a more efficient and scalable alternative without compromising food safety. As highlighted by recent studies, traditional audits that rely on manual processes and human judgment are becoming outdated compared to AI-based systems that deliver faster, more accurate, and consistent results (Saifudin et al., 2025). However, despite the growing recognition of AI's potential in quality assurance, limited empirical research has explored its direct application in routine GMP and SSOP audits within real-world F&B catering environments. This gap underscores the need for studies that evaluate how AI-driven tools perform in comparison to established manual auditing practices, particularly in settings with high operational complexity.

Advancements in computer vision and artificial intelligence (AI) offer transformative solutions to persistent challenges across industries. Image analyzer technologies, driven by machine learning algorithms, have shown strong potential in automating quality control processes across multiple sectors (Kulkarni & Bansai, 2024). Studies have illustrated the effectiveness of computer vision techniques in detecting anomalies, assessing environmental hygiene, and ensuring compliance with regulatory standards, thereby supporting high-precision quality assurance (Paneru & Jeelani, 2021; Scime & Beuth, 2018). Particularly in manufacturing, computer vision has been successfully applied to tasks such as defect detection, packaging inspection, and employee safety monitoring, showcasing its adaptability across various quality control domains (Zhao et al., 2014). Furthermore, advancements in computer vision tracking methodologies have been employed in biomedical imaging to monitor compliance and track critical variables with high precision, suggesting potential cross-sectoral applications (Kang Li et al., 2008).

In the context of food safety, recent studies have shown that AI and computer vision systems can detect surface contamination, monitor hygiene practices, and analyze compliance in food processing environments with promising accuracy and speed (Chen & Yu, 2022; Dhal & Kar, 2025; Kuppusamy et al., 2024). These technologies reduce the dependency on human judgment, minimize audit subjectivity, and enable more frequent inspections without disrupting operations. Such capabilities are highly relevant for the F&B catering sector, where routine visual checks—such as cleanliness of food-contact surfaces, equipment condition, and personal hygiene—are critical to GMP and SSOP compliance. Despite this potential, the targeted application of automated image analysis for auditing GMP and SSOP compliance in food and beverage (F&B) establishments remains limited, highlighting the need for empirical validation and contextual adaptation.

Given the proven capabilities of computer vision systems in industries with stringent quality demands, there is a clear opportunity for further innovation and empirical validation to extend these technologies into routine compliance auditing within the F&B sector. However, the effectiveness of AI systems in audits is highly influenced by the way prompts—user instructions—are formulated. Research has shown that even subtle changes in prompt wording can significantly impact the quality and accuracy of AI outputs across different domains (Guo et al., 2024; Nguyen et al., 2024). In the context of AI-driven audits, the ability to craft precise, context-aware prompts is essential to ensure that the system generates relevant, consistent, and actionable results

This research seeks to bridge the gap between traditional manual auditing methods and emerging digital technologies by introducing an image analyzer-based approach to assess GMP and SSOP compliance. The objectives of this study are: (1) to identify which GMP and SSOP procedures are visually detectable and suitable for image analysis, (2) to collect and analyze images from three F&B establishments specializing in catering services for industrial vendors located in Jakarta, Cikarang, and Karawang, (3) to utilize an image analyzer system—using varied prompt formulations—to score compliance based on uploaded pictures and predefined audit criteria, and (4) to compare the results of automated image-based audits with those obtained through conventional manual audits. By addressing these objectives, the study aims to evaluate the feasibility, reliability, and practical implications of implementing image analyzer technology as a

Table 1. Three prompts used for AI-based image analysis

No	Code	Prompt	Reason
1	P1	Evaluate the uploaded images based on GMP and SSOP compliance standards. Assign a score from 1 (very poor) to 10 (excellent) for each listed criterion. Focus only on observable visual elements.	A standard prompt intended for neutral, objective visual assessment. It mimics a typical audit process by focusing only on clearly visible conditions, avoiding any subjective interpretation
2	P2	Critically assess the uploaded images for potential non-compliance with GMP and SSOP standards. Highlight any possible deficiencies, even minor ones. Provide scores (1–10) and brief notes for each observation	A stricter prompt designed to encourage critical evaluation. It asks the AI to detect even minor deviations, simulating the behavior of a conservative auditor who prioritizes safety and thoroughness
3	P3	Review the uploaded kitchen images considering practical food safety operations under GMP and SSOP standards. Allow acceptable tolerances for minor imperfections if they do not pose significant risks. Score each point (1–10)	A moderate prompt that applies practical judgment. It allows minor non-critical flaws to be tolerated, reflecting the approach of an experienced auditor who understands operational realities.

supporting tool for food safety inspections in the F&B catering sector.

Materials and Methods

Selection of GMP and SSOP Criteria for Image Analysis

The research began by reviewing the Good Manufacturing Practices (GMP) and Sanitation Standard Operating Procedures (SSOP) standards applicable to the food and beverage (F&B) industry, particularly F&B catering services providing daily meals for industrial vendors. From the 18 GMP points regulated under the Regulation of the Minister of Industry No. 75/M-IND/PER/7/2010, and the 10 SSOP points commonly referenced in food safety programs, criteria that are observable through visual inspection were selected (Government of the Republic of Indonesia, 2019; Ministry of Industry of the Republic of Indonesia, 2010). Visual detectability refers to the ability to assess a parameter through images without requiring physical contact (Mohite et al., 2021). Examples of selected criteria include the cleanliness of food-contact surfaces, employee hygiene practices, condition of sanitation facilities, storage arrangements, and evidence of pest control.

Sampling of F&B Catering Establishments and Image Collection

Three F&B catering establishments located in industrial areas of Jakarta, Cikarang, and Karawang were selected through purposive sampling, targeting vendors that provide daily meal services to industrial clients. Each establishment was visited to capture real-time images of their kitchen and food handling processes. For each establishment:

a. A total of 15-20 images meeting the image analysis criteria were captured.
b. Images were taken under consistent lighting and from standard angles to ensure comparability.
c. Images focused on key GMP and SSOP aspects, such as food preparation areas, storage zones, sanitation stations, and employee practices.

Images were collected using an iPhone 11 Pro Max, which features a triple-lens system with a 12-megapixel resolution, enabling high-quality image capture under varying lighting conditions. A standardized image acquisition protocol was implemented, involving consistent ambient lighting, fixed angles (approximately 45–90 degrees), a stable distance of around 1 meter from the subject, and steady handheld positioning to reduce motion blur. Prior to analysis, all images were reviewed to ensure clarity, proper focus, and framing consistency for reliable visual evaluation.

Image Analysis Procedure

The collected images were analyzed using an image analyzer system powered by OpenAI's ChatGPT-4o. Based on previous studies, ChatGPT-4o has proven to deliver remarkably accurate and error-free results within a short time, even outperforming human capabilities in image analysis (Johnson et al., 2023). The system was specifically designed to assess compliance with Good Manufacturing Practices (GMP) and Sanitation Standard Operating Procedures (SSOP). The analysis was performed through the following steps:

1. Image Upload
   15–20 images representing various kitchen areas and activities were uploaded into the image analyzer system for each establishment. To ensure consistency and minimize potential bias, each set of images was uploaded and processed three times. The average score from the three uploads was used as the final score for each criterion.
2. Audit Form Upload
   A structured audit form was uploaded alongside the images. The form was adapted from Indonesia's Ministry of Industry Regulation No. 75/M-IND/PER/7/2010 for GMP and aligned with standard SSOP documentation as recommended by Codex Alimentarius. It included a checklist of selected GMP and SSOP visual criteria and a scoring rubric on a scale of 1 to 10, where a score of 1 indicated very poor conditions and 10 indicated excellent compliance. This design ensured technical integration with existing regulatory frameworks and audit documentation standards used in both national inspections and third-party certifications.
3. Prompt Input
   Before automated image processing, three different text-based prompts were provided to guide the AI's evaluation process. These prompts

Table 2. Suitability of GMP criteria for image analysis

No.	GMP Criteria	Suitable for Image Analysis	Remarks
1	Location, Building Condition, and Facilities	Yes	Visible cleanliness and maintenance
2	Plant and Facility Design	Yes	Layout and organization observable
3	Equipment and Utensil Sanitation	Yes	Surface condition observable
4	Water Supply and Plumbing System	No	Requires functional testing
5	Waste Disposal	No	Requires process flow assessment
6	Personal Hygiene	Yes	Protective clothing visible
7	Process Control	No	Requires activity monitoring
8	Pest Control	Partial	Pest indicators partially visible
9	Storage and Distribution	Yes	Storage arrangement observable
10	Transportation	No	External conditions not consistently visible
11	Food Recall Program	No	Requires document verification
12	Product Information	No	Requires label/document check
13	Training Program	No	Requires training records
14	Maintenance and Sanitation of Facility	Yes	Floor, wall, ceiling cleanliness observable
15	Control of Physical Contaminants	Yes	Foreign object presence partially visible
16	Inspection, Testing, and Monitoring	No	Requires laboratory testing
17	Handling and Storage of Chemicals	Yes	Storage condition observable
18	Documentation and Recordkeeping	No	Requires document review

instructed the system to assess the uploaded images in accordance with the GMP and SSOP criteria listed in the audit form, with each prompt reflecting a different interpretive approach—neutral, critical, and practical. This approach aligns with common audit practices that involve varying levels of scrutiny, allowing the system to simulate different auditor perspectives. Prompt variation was essential to evaluate the system's sensitivity and consistency, as subtle changes in instructions can influence AI performance (Guo et al., 2024; Nguyen et al., 2024). The three prompts are summarized in Table 1.

4. Automated Image Processing
   The AI system then automatically analyzed the uploaded images against the checklist and rubric. By referencing the structured audit form and mapping visual inputs to predefined compliance indicators, the system generated numeric scores for each criterion. This output is technically compatible with digital audit logs and can be exported into standard compliance reporting formats, facilitating integration with internal quality assurance records and external regulatory audits.

Manual Audit Procedure

In parallel with the automated audit, a manual audit was conducted by three independent trained auditors following the same audit form and scoring system. Each auditor individually assessed the physical conditions of the establishments based on direct observations of the same GMP and SSOP criteria. The final manual audit score for each criterion was calculated by taking the average score from the auditors to ensure objectivity and minimize individual bias.

Data Analysis

Data from the AI image analysis using three different prompts (P1, P2, and P3) and from the manual audits were compiled for each establishment. For the AI analysis, the mean and standard deviation were first calculated for each prompt to summarize central tendency and variability. A preliminary paired samples t-test was conducted to evaluate whether there were significant differences among the results produced by the different prompts. If no significant differences ($p > 0.05$) were found between the prompts, the average AI score across the three prompts was used as the final AI-based result. Only the criteria without significant differences among prompts were subsequently compared with the manual audit results. To assess differences between the AI-based results and manual audit scores, a paired samples t-test was performed at a 5% significance level using IBM SPSS Statistics 27.0. If the assumptions for the paired t-test were not met, a descriptive analysis was conducted by comparing the mean scores to evaluate consistency and identify potential discrepancies between the two methods.

Results and Discussion

GMP and SSOP Criteria Suitable for Image Analysis

The selection of criteria from Good Manufacturing Practices (GMP) and Sanitation Standard Operating Procedures (SSOP) was based on the principle of visual detectability, focusing only on aspects that can be reliably assessed through images (Mohite et al., 2021). Table 2 and Table 3 show the evaluation of each GMP and SSOP criterion regarding their suitability for image-based assessment. Based on the evaluation of visual detectability, a total of eight GMP criteria and seven SSOP criteria were identified as suitable for image analysis.

Table 3. Suitability of SSOP criteria for image analysis

No	SSOP Criteria	Suitable for Image Analysis	Remarks
1	Safety of Water and Ice	No	Requires laboratory testing
2	Cleanliness of Food-Contact Surfaces	Yes	Surface condition observable
3	Prevention of Cross-Contamination	Yes	Workflow and separation visible
4	Handwashing, Sanitizing, and Toilet Facilities	Yes	Facility availability and cleanliness observable
5	Protection from Adulterants	Yes	Storage practices observable
6	Proper Labelling, Storage, and Use of Toxic Compounds	Yes	Labelling and placement observable
7	Employee Health Conditions	No	Requires medical verification
8	Exclusion of Pests	Yes	Pest traps and indicators observable
9	Storage and Handling of Cleaning Materials	Yes	Storage area observable
10	Monitoring and Recordkeeping	No	Requires document checking

In both tables, criteria related to visible and physical attributes such as surface cleanliness, layout organization, personal hygiene (appearance), storage arrangement, and pest indicators were deemed suitable for AI analysis. These observations align with the fundamental capability of AI, particularly computer vision models, which excel at recognizing patterns, textures, and anomalies from visual input. Computer vision models like convolutional neural networks (CNNs) are trained to detect features such as dirt, damage, improper storage, and visible contamination (Challa, 2023). Therefore, criteria that rely primarily on visual information are well-suited for AI image analysis, as confirmed by high suitability ratings in both GMP and SSOP evaluations.

Conversely, several GMP and SSOP criteria were categorized as unsuitable for image analysis. These include aspects that require functional testing, process monitoring, document verification, or laboratory analysis, such as water supply and plumbing system, waste disposal processes, training programs, food recall programs, and monitoring and recordkeeping. The limitation stems from the fact that AI vision systems currently lack the ability to interpret invisible or abstract data, such as microbiological safety, chemical residues, internal procedures, or the validity of paperwork (Chen & Yu, 2022; Mohite et al., 2021). This technical limitation highlights the boundary between perceptual tasks, where AI is strong, and cognitive-analytical tasks, where human intervention remains essential (Yam et al., 2021).

The accuracy and reliability of AI-driven image analysis are also highly influenced by the quality of the images used. In this study, efforts were made to standardize image capture through consistent lighting, angles, and distance; however, minor variations in environmental conditions (e.g., shadows, glare, low contrast) may still affect how the AI interprets visual cues. For example, dim lighting or reflections on stainless steel surfaces can obscure contaminants or create false positives, while cluttered backgrounds may reduce the AI's ability to detect specific objects or cleanliness indicators accurately. These limitations emphasize the importance of image standardization protocols in AI-assisted audits. To improve consistency and minimize variation in future applications, image capture protocols could be further refined using fixed camera mounts, controlled lighting setups, and AI-compatible calibration targets placed in the scene to assist with scale and focus.

Evaluation of Differences Between Prompts

The evaluation of AI compliance scores across three prompts (P1, P2, P3) for GMP and SSOP criteria, as shown in Tables 4 and 5, revealed that most visual criteria were consistently assessed regardless of prompt variation. In GMP evaluation, criteria such as Location, Building and Facilities; Equipment and Utensil Sanitation; Personal Hygiene; Maintenance and

Table 4. Comparison of AI-based compliance scores across three prompts (P1, P2, P3) for GMP criteria. Different superscript letters indicate significant differences ($p < 0.05$) between prompts.

GMP Criterion	P1 Mean ± SD	P2 Mean ± SD	P3 Mean ± SD
Location, Building, and Facilities	4.00 ± 1.00^{a}	4.33 ± 0.58^{a}	4.00 ± 1.15^{a}
Plant and Facility Design	5.00 ± 1.00^{b}	6.00 ± 0.82^{a}	6.67 ± 0.58^{a}
Equipment and Utensil Sanitation	5.67 ± 0.58^{a}	5.33 ± 0.58^{a}	5.67 ± 1.15^{a}
Personal Hygiene	6.33 ± 1.15^{a}	6.00 ± 0.47^{a}	6.00 ± 0.82^{a}
Storage and Distribution	4.00 ± 1.00^{b}	5.33 ± 0.58^{a}	5.67 ± 1.15^{a}
Maintenance and Sanitation of Facility	4.67 ± 1.15^{a}	4.33 ± 1.15^{a}	4.67 ± 0.58^{a}
Control of Physical Contaminants	5.33 ± 0.58^{a}	5.67 ± 0.82^{a}	5.67 ± 0.58^{a}
Handling and Storage of Chemicals	4.00 ± 1.00^{b}	5.00 ± 0.82^{a}	5.33 ± 1.15^{a}

Table 5. Comparison of AI-based compliance scores across three prompts (P1, P2, P3) for SSOP criteria. Different superscript letters indicate significant differences (p < 0.05) between prompts.

SSOP Criterion	P1 Mean ± SD	P2 Mean ± SD	P3 Mean ± SD
Cleanliness of Food-Contact Surfaces	5.33 ± 0.58[a]	5.67 ± 0.58[a]	5.00 ± 1.00[a]
Prevention of Cross-Contamination	6.00 ± 0.00[a]	5.00 ± 1.00[b]	6.67 ± 0.58[a]
Handwashing, Sanitizing, and Toilet Facilities	4.33 ± 0.58[ab]	5.67 ± 0.58[a]	4.00 ± 0.00[b]
Protection from Adulterants	5.00 ± 1.00[a]	5.33 ± 0.58[a]	5.00 ± 1.00[a]
Proper Labeling, Storage, and Use of Toxic Compounds	6.00 ± 0.00[a]	6.33 ± 0.58[a]	5.67 ± 1.15[a]
Exclusion of Pests	5.33 ± 0.58[ab]	7.00 ± 1.00[a]	5.00 ± 1.00[b]
Storage and Handling of Cleaning Materials	4.67 ± 0.58[a]	4.33 ± 0.58[a]	4.67 ± 1.15[a]

Sanitation of Facility; and Control of Physical Contaminants showed no significant differences among prompts, suggesting stable AI performance for visually straightforward indicators. Similarly, SSOP criteria such as Cleanliness of Food-Contact Surfaces; Protection from Adulterants; Proper Labelling and Storage of Toxic Compounds; and Storage and Handling of Cleaning Materials were scored consistently across prompts.

However, significant prompt-induced differences were observed for Plant and Facility Design, Storage and Distribution, and Handling and Storage of Chemicals under GMP, and for Prevention of Cross-Contamination, Handwashing, Sanitizing and Toilet Facilities, and Exclusion of Pests under SSOP. These criteria involve more contextual and operational interpretation, which tends to be influenced by how the AI is instructed to prioritize visual information. This variation in scores can be attributed to the distinct logic embedded in each prompt. Prompt 1 (P1) represents a neutral and objective baseline, where the AI evaluates only what is clearly visible without subjective judgment. It reflects a standard checklist-style audit, and as such, often generates balanced scores. In contrast, Prompt 2 (P2) is framed to encourage critical inspection. By asking the AI to "highlight any possible deficiencies, even minor ones," it pushes the system to be vigilant and risk-averse, much like a conservative auditor seeking maximum compliance. This results in stricter scores, as the AI penalizes even slight deviations such as disorganized storage, improperly hung tools, or unclear separation of zones. Consequently, criteria that require contextual understanding, like facility design or pest prevention, are more harshly evaluated under this prompt.

On the other hand, Prompt 3 (P3) reflects practical flexibility, simulating the mindset of a seasoned auditor who allows minor imperfections as long as they do not compromise food safety. This prompt tends to yield more lenient scores, especially in borderline situations where visual imperfections do not clearly signal non-compliance. For example, slightly worn surfaces or minimal clutter in non-critical zones may be tolerated, resulting in higher compliance ratings. These findings align with recent literature on prompt engineering, which demonstrates that even small variations in wording can substantially affect AI-generated outputs in both text-to-image and domain-specific reasoning tasks (Guo et al., 2024; Nguyen et al., 2024). While AI can consistently evaluate clear-cut visual indicators, its performance on more ambiguous or context-sensitive criteria can vary significantly depending on the interpretive framing provided through prompts. This emphasizes the critical importance of prompt standardization when deploying AI in regulatory or operational audits. Without harmonized prompt instructions, audit outcomes may differ substantially, even when analyzing the same images, thereby affecting reliability and comparability.

Table 6. Comparison of AI-based and manual audits for Good Manufacturing Practices (GMP) in F&B catering services

	Criteria	F&B A			F&B B			F&B C		
		AI Mean ± SD	Manual Mean ± SD	p-value	AI Mean ± SD	Manual Mean ± SD	p-value	AI Mean ± SD	Manual Mean ± SD	p-value
1	Location, Building Condition, and Facilities	4.00 ± 1.00	4.67 ± 1.00	> 0.05	5.33 ± 0.82	5.67 ± 0.47	> 0.05	4.67 ± 1.15	5.67 ± 1.53	> 0.05
2	Plant and Facility Design	5.00 ± 1.00	7.67 ± 0.58	**< 0.05***	5.67 ± 0.58	6.00 ± 1.15	> 0.05	6.00 ± 0.00	7.00 ± 1.00	> 0.05
3	Equipment and Utensil Sanitation	4.33 ± 1.53	4.67 ± 1.00	> 0.05	5.67 ± 0.58	6.00 ± 0.82	> 0.05	4.00 ± 0.00	5.33 ± 0.58	> 0.05
4	Personal Hygiene	6.33 ± 1.15	6.67 ± 1.00	> 0.05	6.00 ± 0.47	6.00 ± 0.00	> 0.05	5.33 ± 1.15	6.67 ± 1.53	> 0.05
5	Storage and Distribution	3.00 ± 1.00	5.67 ± 0.58	**< 0.05***	4.00 ± 0.58	6.00 ± 0.47	**< 0.05***	5.33 ± 1.15	6.33 ± 0.58	> 0.05
6	Maintenance and Sanitation of Facility	4.00 ± 1.00	4.67 ± 0.58	> 0.05	5.00 ± 0.47	5.33 ± 0.47	> 0.05	4.00 ± 0.00	4.33 ± 0.58	> 0.05
7	Control of Physical Contaminants	4.67 ± 1.15	5.33 ± 1.15	> 0.05	5.33 ± 0.58	5.67 ± 0.82	> 0.05	3.33 ± 1.15	4.67 ± 2.31	> 0.05
8	Handling and Storage of Chemicals	3.67 ± 1.53	4.67 ± 1.00	> 0.05	4.00 ± 0.58	6.00 ± 1.00	**< 0.05***	5.33 ± 1.15	6.67 ± 0.58	> 0.05
	Average	4.38 ± 1.00	5.50 ± 1.13		5.13 ± 0.76	5.83 ± 0.25		4.75 ± 0.90	5.83 ± 0.99	

Note: *indicates significant differences (p<0.05)

Table 7. Comparison of AI-based and manual audits for Good Manufacturing Practices Sanitation Standard Operating Procedures (SSOP) in F&B catering services

No.	Criteria	F&B A			F&B B			F&B C		
		AI Mean ± SD	Manual Mean ± SD	p-value	AI Mean ± SD	Manual Mean ± SD	p-value	AI Mean ± SD	Manual Mean ± SD	p-value
1	Cleanliness of Food-Contact Surfaces	4.00 ± 1.00	4.67 ± 1.00	> 0.05	5.67 ± 0.58	6.00 ± 0.82	> 0.05	4.00 ± 0.00	5.00 ± 1.00	> 0.05
2	Prevention of Cross-Contamination	4.00 ± 1.00	5.00 ± 1.00	> 0.05	5.00 ± 0.47	5.33 ± 0.47	> 0.05	5.33 ± 1.15	6.67 ± 2.31	> 0.05
3	Handwashing, Sanitizing, and Toilet Facilities	4.00 ± 1.00	5.00 ± 1.00	> 0.05	5.00 ± 0.47	5.33 ± 0.58	> 0.05	3.33 ± 1.15	4.00 ± 2.00	> 0.05
4	Protection from Adulterants	4.00 ± 1.00	5.00 ± 1.00	> 0.05	5.00 ± 0.58	5.33 ± 0.82	> 0.05	4.00 ± 0.00	5.33 ± 1.15	> 0.05
5	Proper Labeling, Storage, and Use of Toxic Compounds	4.67 ± 0.58	5.33 ± 1.15	> 0.05	5.67 ± 0.58	6.00 ± 1.00	> 0.05	5.33 ± 1.15	6.67 ± 1.15	> 0.05
6	Exclusion of Pests	4.00 ± 1.00	5.00 ± 1.00	> 0.05	5.33 ± 0.58	5.67 ± 0.58	> 0.05	3.33 ± 1.15	4.67 ± 2.31	> 0.05
7	Storage and Handling of Cleaning Materials	4.00 ± 1.00	5.00 ± 1.00	> 0.05	5.33 ± 0.58	5.67 ± 0.47	> 0.05	5.33 ± 1.15	6.33 ± 2.08	> 0.05
	Average	4.10 ± 0.25	5.00 ± 0.19		5.29 ± 0.30	5.62 ± 0.30		4.38 ± 0.93	5.52 ± 1.05	

Note: *indicates significant differences ($p<0.05$)

Evaluation of GMP and SSOP Compliance Using Automated Image Analysis and Manual Audits

The evaluation of compliance with Good Manufacturing Practices (GMP) and Sanitation Standard Operating Procedures (SSOP) was performed across three F&B catering facilities using both manual audits and automated image analysis. The results, summarized in Table 6 and 7. Table 6 presents a comparison between AI-based and manual audits assessing Good Manufacturing Practices (GMP) compliance across three F&B catering services (F&B A, F&B B, and F&B C). In general, the results show that most criteria evaluated by AI were aligned with manual audits, as indicated by p-values greater than 0.05 in most cases. This suggests that AI-based assessments were consistent with human evaluations in aspects such as location and facility conditions, equipment sanitation, personal hygiene, and control of physical contaminants. The averages for AI and manual scores across all F&B catering services were relatively close, indicating that the AI system was able to mimic human judgment within acceptable variability (Chein et al., 2024).

However, significant differences ($p < 0.05$) were observed in specific criteria, notably in plant and facility design, storage and distribution, and handling and storage of chemicals. For instance, in F&B A, AI scores for plant and facility design and storage, and distribution were significantly lower than those obtained from manual audits, highlighting that AI was more critical or sensitive in detecting deficiencies in facility layout and material handling practices. A similar pattern was seen in F&B B for storage and distribution, and for handling and storage of chemicals. These discrepancies could be related to inherent limitations of AI systems, particularly their sensitivity to visible defects while lacking the contextual judgment human auditors apply. AI models often face challenges in interpreting nuanced or borderline cases, leading to potential overestimation of non-compliance when human auditors might consider certain conditions acceptable (Chong et al., 2022) .

Table 7 presents a comparison between AI-based and manual audits for Good Manufacturing Practices Sanitation Standard Operating Procedures (SSOP) across three F&B catering services (F&B A, F&B B, and F&B C). Overall, the results indicate that AI evaluations were largely consistent with manual audits, as reflected by p-values greater than 0.05 across all SSOP criteria evaluated. This shows that AI-based image analysis was able to closely match human evaluations in key sanitation areas, such as the cleanliness of food-contact surfaces, prevention of cross-contamination, availability of handwashing facilities, and pest control. On average, AI and manual inspection scores followed a similar pattern, although AI scores were slightly lower across the three services. This suggests that the AI system tends to be a bit more conservative or stricter than human inspectors. Compared to human inspection, machine vision techniques offer advantages like higher efficiency, lower cost, greater objectivity, and are now widely used in industrial defect inspections (Wang, 2022).

Interestingly, no statistically significant differences were observed across any SSOP criteria, in contrast to the findings in GMP evaluations (Table 6). This may be attributed to the more visually detectable and standardized nature of sanitation issues, which AI systems are better equipped to identify (Johnson et al., 2023). Tasks such as detecting cleanliness, proper labeling of toxic materials, or pest exclusion can often be objectively assessed through image recognition algorithms without requiring extensive contextual interpretation. AI, particularly computer vision models, performs well in structured, high-visibility tasks like surface cleanliness detection and contamination monitoring (Dhal & Kar, 2025; Kuppusamy et al., 2024). Therefore, AI might be especially suitable for SSOP audits where visual cues are clear and objective.

Overall, this study contributes new insights by systematically demonstrating which GMP and SSOP criteria are best suited for AI image analysis and where limitations still exist. This research provides a more comprehensive comparison across multiple real-world facilities using direct head-to-head evaluation against human auditors. The findings highlight the need for future

AI audit tools to incorporate multimodal inputs, such as integrating visual data with sensor outputs or digital records, to bridge gaps in areas where visual assessment alone is insufficient. As AI technologies evolve, hybrid approaches combining AI automation with human expertise will likely offer the most effective strategy for ensuring comprehensive, accurate, and reliable food safety audits.

Conclusion

This study provides initial insights into the potential of AI-driven image analysis for assessing GMP and SSOP compliance in food and beverage catering establishments, particularly for visually observable criteria. While some prompt-induced differences were statistically significant, especially for context-sensitive aspects like facility design and storage practices, most AI-generated scores did not differ significantly from manual audit results ($p > 0.05$), indicating general consistency. However, due to the absence of quantitative agreement metrics such as correlation coefficients or inter-rater reliability measures, these findings should be interpreted as indicative rather than conclusive. AI systems also tended to provide slightly stricter evaluations, underscoring the importance of standardized prompt formulation and continued human oversight. Integrating AI tools into food safety audits may offer meaningful improvements in audit consistency and efficiency, but further studies with more robust statistical validation are needed to confirm reliability across diverse operational settings.

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